REMARKS

Claims 1-2, 6-8, 16-17, 51-56, 58-60, 79-85 and 96 are pending in this application. By this Amendment, claims 7, 16 and 56 are amended and claims 97-112 are canceled without prejudice to our disclaimer of the subject matter disclosed therein. Reconsideration of the application is respectfully requested.

Applicant thanks the Examiner for an indication that claims 1-2, 6, 51-55, 59-60, 79-85 and 96 are allowed.

The Office Action provisionally elects claims 97-98 for non-statutory obviousness-type double patenting over claims 1-18 of co-pending Application No. 10/357,708; claim 56 over claims 1-30 of co-pending Application No. 10/332,057; and claims 97-98 over claims 1-30 of co-pending Application No. 10/332,057. The cancellation of claims 97-98 renders their rejection moot.

Moreover, with respect to claim 56, claims 1-30 of co-pending Application No. 10/332,057 are patentably distinct from claim 56 of the above-identified application. Claims 14-16, 18-25, 27-30 of co-pending Application No. 10/332,057 teach information light that is spatially modulated in phase based on information to be recorded, composite light which is generated by superimposing the reproduction light on the reproduction-specific reference light, and detecting means that detects the composite light. Support for these features can be found in Application No. 10/332,057 at, for example, paragraph [0101] and Fig. 3. These features are <u>not</u> part of the subject matter of 56 of the above-identified application, and are also not obvious over claim 56. Thus, withdrawal of the provisional double patenting rejection is respectfully requested.

The Office Action rejects claims 7 and 56 under 35 U.S.C. §103(a) over Curtis et al. (U.S. Patent No. 5,719,691) in view of Rembault (U.S. Patent No. 4,025,731) and Gabor (U.S. Patent No. 3,899,240); claims 97-98 under 35 U.S.C. §103(a) over Curtis in view of

Rembault and Gabor; claims 16 and 99 under 35 U.S.C. §103(a) over Curtis in view of Rembault and Gabor and further in view of Liu et al. (U.S. Patent No. 6,272,095); and claims 8, 17 and 58 under 35 U.S.C. §103(a) over Curtis in view of Rembault, Gabor, Liu, Van Rosmalen (U.S. Patent No. 4,638,471), Reid et al. (U.S. Patent No. 4,213,193) and Hays et al. (U.S. Patent No. 5,777,760). The rejections are respectfully traversed.

With respect to claims 97-99, their cancellation renders their rejection moot. Moreover, none of the applied references, alone or in combination, disclose or suggest an optical information reproducing apparatus for reproducing two-dimensional digital pattern information utilizing holography from an optical recording medium having a reflecting layer and information recording layer that includes at least a reproducing optical system for illuminating the information recording layer with the reference light for reproduction on a same side of the information recording layer that is illuminated with the information light and the reference light for recording, using the reflecting layer as a reference plane to generate reproduction light, and for collecting reproduction light carrying the two dimensional digital pattern information on the same side of the information recording layer that is illuminated with the reference light for reproduction, as recited in independent claim 7 and similarly recited in independent claims 16 and 56.

Curtis teaches holograms within an array that are recorded and/or read out by use of a reference/readout beam produced by illumination of a phase mask (Abstract).

Rembault teaches an optical record that can contain the same track, the transcription of several simultaneous signals and is designed to be read out by means of a light source, the track being formed by fringes whose spacing varies as a function of the instantaneous amplitude of the signal being transcribed (Abstract).

Gabor teaches a method for making a discriminating hologram which can be used to distinguish similar subjects, and a method for distinguishing these similar subjects using the discriminating hologram (Abstract).

Liu teaches an optical memory for storing and/or reading data on an optical disk, the optical disk incorporating a material in which holographic gratings can be created at plural locations within the disk, and an electro-optical head which is capable of creating these holographic gratings at any one of the plural locations (Abstract).

However, none of these references disclose or suggest using the reflecting layer as part of the optical information reproduction apparatus. For example, as indicated in the paper entitled "Holographic Versatile Disk System," attached to this Amendment for the Examiners' convenience, a defocused margin during reproducing of the holographic versatile disk that uses collinear technology exists. Accordingly, in collinear technology applications, it is important that the reproducing optical apparatus generates the focus <u>using the reflecting layer as a reference plane</u>, as recited independent claims 7, 16, and 56. Also, holographic information storage systems have been good candidates for recording and reproducing technology because of their large storage capacities and high transfer rates. Furthermore, none of the applied references disclose or suggest a reproducing optical apparatus that includes using the reflecting layer as a reference plane to illuminate with the reference light for reproduction, as recited in independent claims 7, 16 and 56. Accordingly, independent claims 7, 16 and 56, and their dependent claims, are patentable over the applied references. Thus, withdrawal of the rejections of the claims under 35 U.S.C. §103(a) is respectfully requested.

Finally, Van Rosmalen, Reid and Hays fail to cure deficiencies in Curtis, Rembault, Gabor and Liu in disclosing and rendering obvious the features of claims 8, 15 and 17, including the limitations of independent claims 7, 16 and 56.

In view of the foregoing, it is respectfully submitted that this application is in condition for allowance. Favorable reconsideration and prompt allowance of claims 1-2, 6-8, 16-17, 51-56, 58-60, 79-85 and 96 are earnestly solicited.

Should the Examiner believe that anything further would be desirable in order to place this application in even better condition for allowance, the Examiner is invited to contact the undersigned at the telephone number set forth below.

Respectfully submitted,

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JAO:TMN/amw

Attachment:
"Holographic Versatile Disk System," H. Horimaamai and X.Tan

Date: April 20, 2006

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Holographic Versatile Disc System

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ABSTRACT

A Holographic Versatile Disc (HVD) system, using Collinear Technologies for a high capacity and high data transfer rates storage system, is proposed. With its unique configuration the optical pickup can be designed as small as a DVD's, and can be placed on one side of the disc. With the HVD's special structure, the system can servo the focus/track and locate reading/writing address. A unique selectable capacity recording format of HVD and its standardization activity are also introduced. Experimental and theoretical studies suggest that the tilt, wavelength, defocus and de-track margins are wide enough to miniaturize the HVD system at a low cost. HVD systems using Collinear Technologies will be compatible with existing disc storage systems, like CD and DVD, and will enable us to expand its applications into other optical information storage systems.

Keywords: holographic information storage system, optical disc, optical memory, volumetric recording, holography

1. INTRODUCTION

Optical discs based on the bit-by-bit method, such as CD and DVD, for storing sound, movies, photos and other digital contents are widely used in our daily life. The new product Blu-ray Disc that appeared last year was developed for high-definition video and high-capacity software applications. These new optical discs achieve up to 27 GB high-density recording on a single-sided single-layer disc, by employing a short wavelength blue-violet laser and a large numerical aperture (NA=0.85) field lens to minimize its beam spot size on the disc. In addition, by using a disc structure with a 0.1mm optical transmittance protection layer, it is possible to diminish aberrations caused by disc tilt. For instance the bit-by-bit method is near to the limitations of recording density. Now, we are faced with the question: what is the next generation of optical discs?

Holographic information storage systems (HISS) have been a good candidate for a volumetric recording technology, due to their large storage capacities and high transfer rates. Recently, revival of activity in HISS has resulted from the dramatic developments in the requisite components for such a system, such as laser technology, spatial light modulators (SLM) and complementary metal-oxide semiconductor (CMOS) image sensors [1]. Within the last several years, unique demonstration platforms using digital volume holography have been proposed [2-4]. However, these storage systems, so called 2-axis holography, still have essential issues for practicality. Firstly, the reference beam of the recording and the reading process is separated spatially with an off-axis optical configuration, which results in a complex and large optical system preventing the system from miniaturization. Secondly, to increase the storage density, angle multiplexing [2], phase-coded multiplexing [3], wavelength multiplexing [4], and other methods [5,6] are employed normally. Spatial fluctuation of the storage media should then be strictly controlled, and a large and heavy damping system is indispensable. This, in turn, prevents the removability and interchangeability of the media as well as the miniaturization of the system. Thirdly, the hologram media are transmission type and there isn't any address information on the discs, as a result, no data interchangeability is assured. Furthermore this holographic storage technology completely differs from other existing storage systems, like bit-by-bit storage methods, and the hologram media cannot be compatible with conventional storage media.

Holographic Versatile Disc (HVD) system using Collinear Technology, a new technology for HISS, is proposed and demonstrated by OPTWARE Corporation [7]. This technology is able to solve the problems mentioned above, and can produce a small, practical HISS more easily than conventional 2-axis holography. In this paper, we propose a preformatted reflective layer that is widely used to assure data interchangeability in the optical disc technologies (like CD and DVD) and is applied to HVD using Collinear Technology. The construction of the optical setup, a two-dimensional (2-D) digital data page format, the multiplexing recording characteristics, and the structure of the HVD being employed in this technology are presented. A unique selectable recording format of HVD and its standardization activities are introduced. The experimental and theoretical analysis of the tilt and wavelength margins of the HVD system, as

compared with conventional 2-axis holography, and the defocus and de-track margins, as compared with DVD, are also discussed.

2. COLLINEAR TECHNOLOGY

Collinear Technology as a new reading and writing method for a holographic storage system is very promising and differs from conventional 2-axis holography. The unique feature of this technology is that 2-D page data are recorded as volume holograms generated by a co-axially aligned information beam and a reference beam, which are displayed simultaneously by the same SLM, and interfere with each other in the recording medium (disc) through a single objective lens.

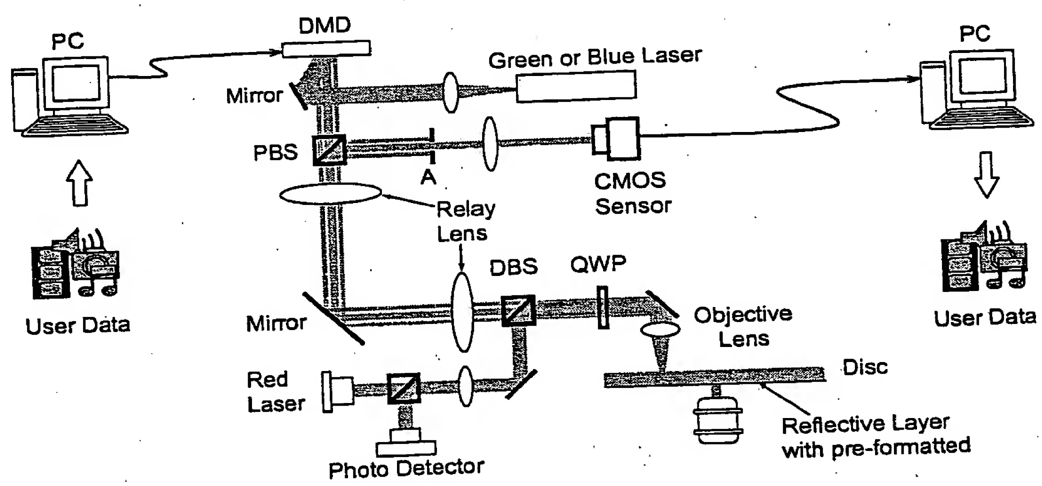

Figure 1. Optical configuration of the HVD system as a new reading and writing technology for a HISS. The green or blue laser and the red laser mean a laser beam with wavelengths of green or blue light and red light.

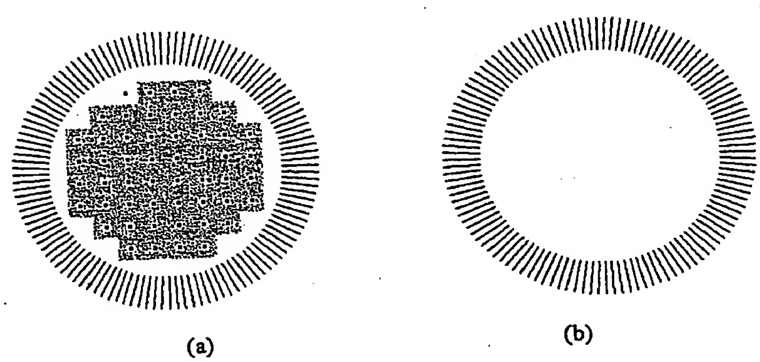

Figure 2. A pair of two-dimensional digital data page patterns is used in the HVD. (a) write pattern, and (b) read pattern are displayed on the SLM.

Figure 1 shows the schematic optical configuration of Collinear Technology and Fig. 2 shows one pair of the 2-D data page patterns. The linear polarization state collimated laser beam with green (or blue) wavelength is used for both writing and reading holograms. In the writing process, a combined image of the information pattern (center part) and the reference pattern (outer ring part) is displayed on the digital micro-mirror device (DMD) used as the SLM, as shown in Fig. 2(a). The laser beams modulated by the DMD, with p-polarization, pass through the polarizing beam splitter (PBS) and

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then incident upon a quarter-wave plate (QWP). The laser beams, which are converted from a p-polarized state to a circularly polarized state by the QWP, are focused onto the holographic recording disc by an objective lens, where they interfere with each other. The interference pattern is recorded as a volume hologram in the disc. In the reading process, only the outer ring pattern, as shown in Fig. 2(b), is displayed on the SLM to be used for creating a reference beam. The p-polarized laser beam passes through the PBS and is converted to a circularly polarized state by the QWP, and is then focused by the same objective lens as used in the recording process. The circularly polarized reconstructed information beam, which is diffracted from the hologram and reflected by the reflective layer in the disc is sent back to the objective lens and passed through the QWP again. The reconstructed beam, which is converted from a circularly polarized state to an s-polarized state, is reflected by the PBS and detected by a high-speed CMOS sensor. A laser with red wavelength is used for optical servo control to adjust the focal point of the objective lens onto the disc correctly and to locate the hologram address in the disc. The servo and address information are pre-formatted in the disc as embossed pits. In order to eliminate the diffraction noise in the recording media caused by the embossed pits, a dichroic mirror interlayer is used to reflect green (or blue) laser beams and let red laser beams pass through. The green (or blue) and red laser beams are combined on the same axis and separated by a dichroic mirror layer in the disc.

The data page format based on the sub-page is used to eliminate the problems of illuminated intensity distribution in a data page, distortion and aberration of the optical system, tilting, and the estimation error caused by amplification. As shown in Fig. 3, the size of a sub-page (24×24 pixels) depends on the parameters and the magnitude of the inhomogeneity of a system. In each sub-page there are 32 byte data symbols (4×4 pixels) and a synchronous mark (8×8 pixels) in its center. The synchronous symbol, which includes a 4×4 pixels rectangular block, is used to locate the sub-page and provide the necessary coordinate information for data decoding. The sorting method and correlation technique which differ from the threshold method are used to distinguish the ON-pixel and OFF-pixel states from the reconstructed image in the decoding process. In this data page format the code rate is 0.5 and the white rate is about 19%.

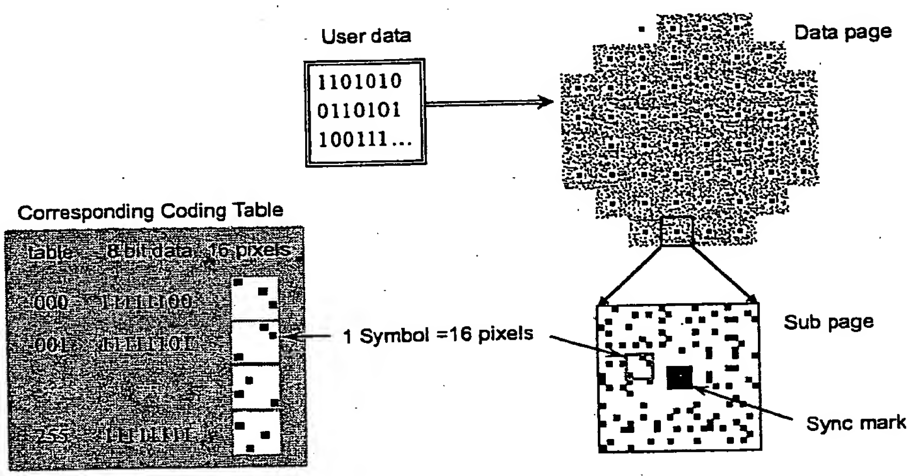

Figure 3. Data page format encoded from the user data to be used in the HVD system.

3. RECONSTRUCTION EXPERIMENT AND SHIFT-SELECTIVITY

In order to develop the HISS using Collinear Technologies, an optical system, as shown in Fig. 1, is setup. A green laser (532nm) is used for both reading and writing holograms and a red semiconductor laser (650nm) is introduced for optical servo control of focusing and addressing the holograms. A 2-D reconstructed data page image is detected by a high-speed CMOS sensor.

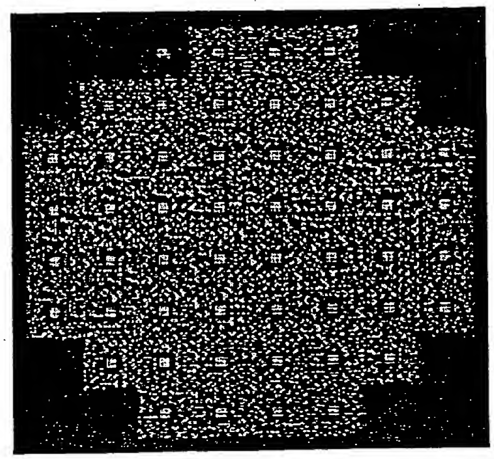

Figure 4. Reconstructed two-dimensional digital data page pattern image from the collinear holographic system.

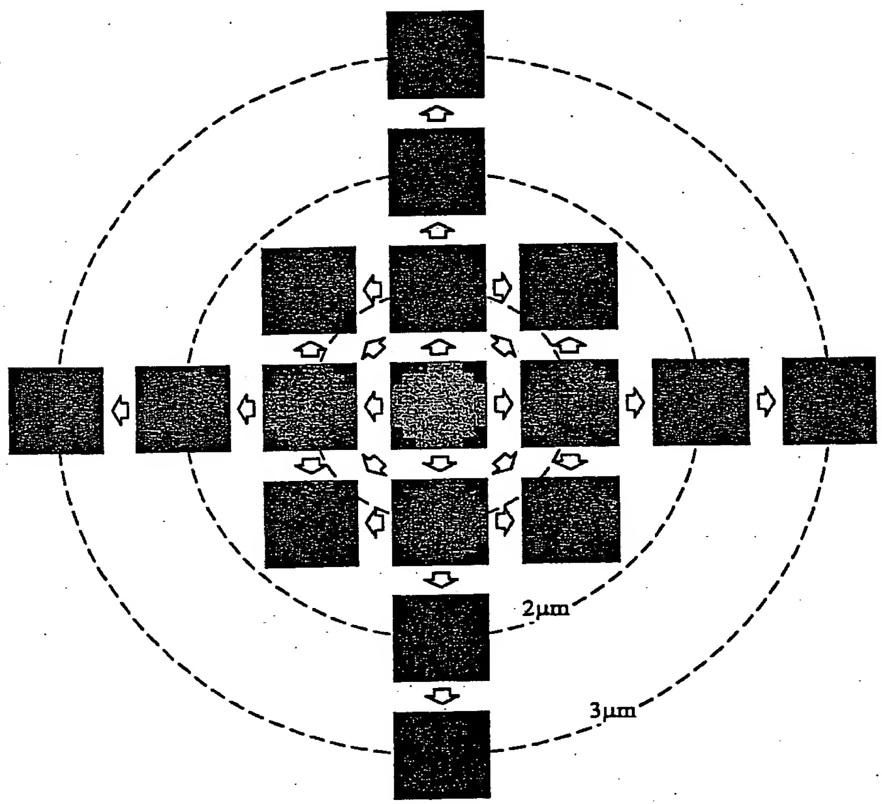

Figure 5. The reconstructed two-dimensional data page images from the hologram by shifting the position of recorded hologram in both radial and tangential directions. The reconstructed images disappeared completely by 3μm shift in both directions, indicating that the shift selectivity of Collinear Technology allows us to record holograms by overlapping at a pitch of at least 3μm.

In detecting the reconstructed image from a HISS the pixel-to-pixel matching method [8,9] has both a high decoding speed and a high transfer rate, but it requires an extremely precise optical system and careful alignment. In order to obtain a low bit error rate, the alignment, distortion and magnification of the lenses must be controlled to about 0.01% [1]. Currently an over sampling method with a ratio of 3 is used in this system. It means that one pixel on the SLM is imaged onto the CMOS with 3×3 pixels. Simple analysis shows that if the over sampling rate between SLM and CMOS pixels is larger than 2, each SLM pixel covers fully at least one CMOS pixel, so even simple decoding algorithm can be effective.

By using the optical configuration, as in Fig. 1, the data page pattern shown in Fig. 2(a) is recorded as a hologram in the disc. The reconstructed 2-D image shown in Fig. 4 is retrieved by the reference pattern, as shown in Fig. 2(b). In this case, the stored data page pattern is set in black and white, and is reconstructed clearly by the Collinear Technology. Up to now, the experiment has shown that pixel errors are generated at random in the data page images. That is, one symbol error corresponds to almost one pixel error in the case of a low number of errors. To ascertain the performance of the recording media we have decided that the number of symbol errors must be lower than 100, that is, when 100 symbol errors correspond to 100 pixel errors.

Using the shift-multiplexing method to increase recording density is suitable for Collinear Technology, because the hologram can be recorded continually by the rotating disc [10]. The shift-selectivity is a very important parameter concerning the capacity of a HISS. The smallest shift-pitch of HVD using Collinear Technology has been investigated, and Fig. 5 shows the reconstructed 2-D image from a hologram, the position of which has been shifted in both radial and tangential directions. The reconstructed image disappeared completely with a 3 μm shift in both directions, indicating that Collinear Technology allows us to record holograms by overlapping at a pitch of at least 3 μm [11].

4. DISC STRUCTURE AND SELECTABLE CAPACITY RECORDING FORMAT

In HVD system, the green (or blue) and red laser beams are combined to the same axis and are transmitted through a single objective lens. For this reason, a special disc structure of HVD is designed. Figure 6 shows the six layers of the HVD structure schematically. The holographic material used in the recording layer is photopolymer. HVD has a reflective layer with pre-formatted address information. Based on this layer, focusing servo and tracking servo technology can be used in the recording and the reconstructing process. This will precisely maintain the distance and the relative position of the objective lens and the disc, and the holograms can be recorded and reconstructed in a HVD accurately even if there is axial deflection or radial runout. Furthermore a vibration isolator is not necessary anymore. Figure 7 shows the electrical signals of address and servo information read from pre-formatted embossed pits by using a red laser.

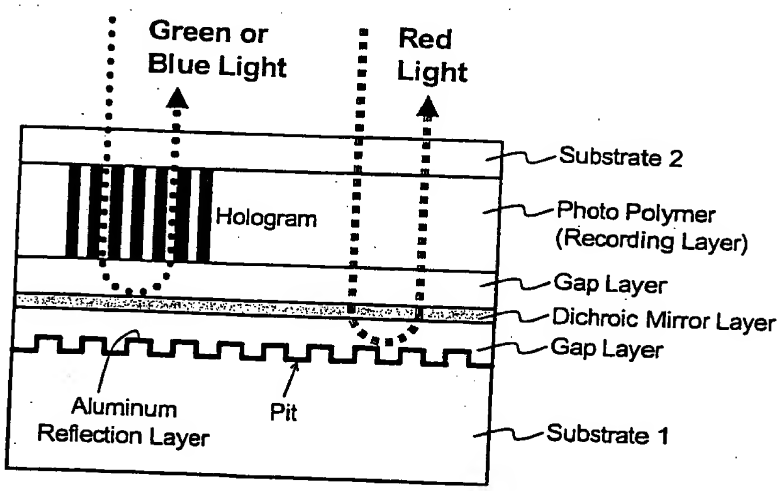

Figure 6. Schematic illustration showing a dichroic reflective structure disc

In order to eliminate the diffraction noise in the recording media caused by the embossed pits, a dichroic mirror interlayer is placed between the recording layer the reflective layer. The red laser beams for optical servo control will reach the pre-formatted reflective layer, however, the green (or blue) laser beams for forming hologram is perfectly reflected by this dichroic mirror interlayer. The experiments have proved that the dichroic mirror interlayer eliminates diffraction noise effectively.

The special disc structure which has mentioned above simplifies the optical systems allowing small and compact packaging on the same side of the disc. This method will enable us to construct a small volumetric optical disc storage system, compatible with existing disc storage systems, like CD and DVD.

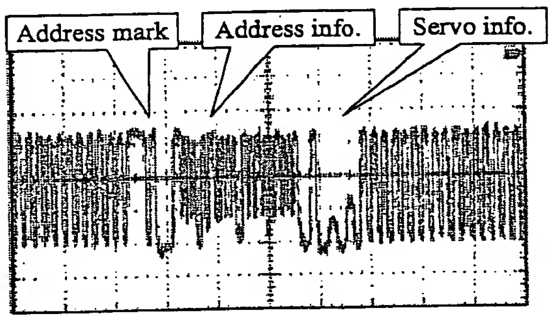

Figure 7. Electrical signal of the pre-formatted embossed -pit

In HVD, the holograms are recorded at a shift pitch in the radial and the tangential directions of the disc, so-called the shift-multiplexing method, and the recording density can be improved by changing this shift pitch. Because the hologram recording layer is separated optically from the pre-formatted layer, the shift pitch can be arbitrarily adjusted based on the location information obtained from the pre-formatted layer, and the storage capacity can be changed freely, this is the conception of the selectable capacity recording format. For example, in the case of a data page size 32Kbit recorded in a ϕ120mm disc, as shown in Fig. 8, a shift pitch of 200GB/disc is 13 μm, 500GB/disc is 8 μm, and 2.2TB/disc is 4μm. Experiments have proven that the shift selectivity of the HVD system is 3μm [7,11]. And the tracing pitch in the pre-formatted layer of HVD used presently is 1.6μm.

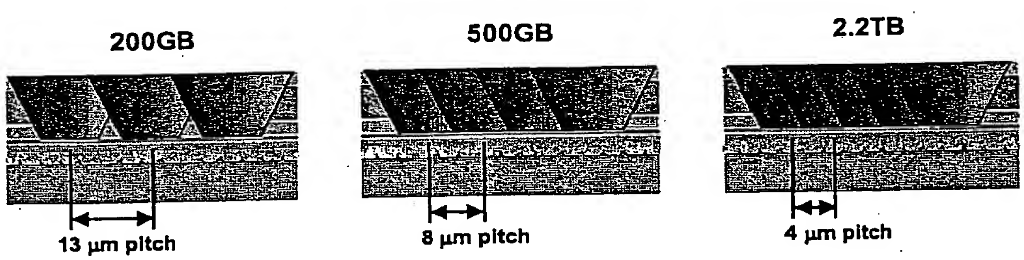

Figure 8. Conceptual diagram of a preformatted reflective layer in HVD is used to assure data interchangeability.

5. SYSTEM MARGINS

In order to produce a small, practical and low cost HVD system, the investigation of system margins is very important. The tilt margin and wavelength margin compared with conventional 2-axis holography, and de-focus and de-track margins compared with DVD have been studied in experiments. In the experiment a thickness of 500 μm media is used.

The tilt margin of the HVD compared with conventional 2-axis holography is shown in Fig. 9. The diffraction efficiency of the hologram is calculated from the sum of the brightness of the center part pixels, which come from the information pattern of a reconstructed image received by CMOS image sensor. At 50% diffraction efficiency, symbol error count is lower than 100, and at this point the tilt angle is up to 0.18 degree. From Fig. 6, it is indicated that the tilt margin of collinear technology is over eight times larger than that of conventional 2-axis holography for the same thickness of the media [1,7].

In order to analyze the wavelength margin, the laser source of HVD system, as shown in Fig. 1, is exchanged to a dye laser pumped by an Ar^+ laser to change the wavelength. In the recording process, the write pattern, as in Fig. 2(a), is recorded into a disc at a certain wavelength. As for the reconstruction process, the reconstructed image of the page pattern is received by a CMOS sensor at a different laser wavelength in the recording process. Experimental results obtained at different laser wavelengths are summarized in Fig. 10. It is noted that the wavelength margin at 50% diffraction efficiency of collinear technology is over three times larger than that of conventional 2-axis holography for the same thickness of the media [1]. The symbol error is counted from a reconstructed image in the decoding process, even if the laser wavelength in the reconstructing process is shifted by $\Delta\lambda$=3nm in the recording process, the symbol error count is lower than 100, and reproduction of user data is possible [12].

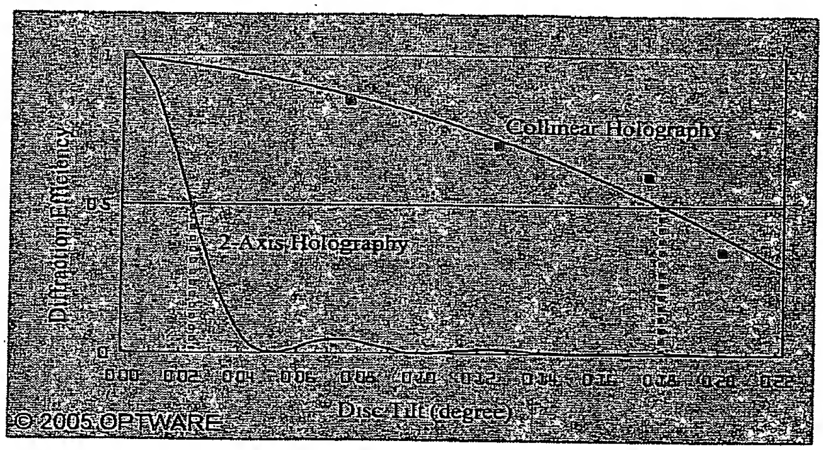

Figure 9. Tilt margin analysis of diffraction efficiency at medium thickness of 500 μm.

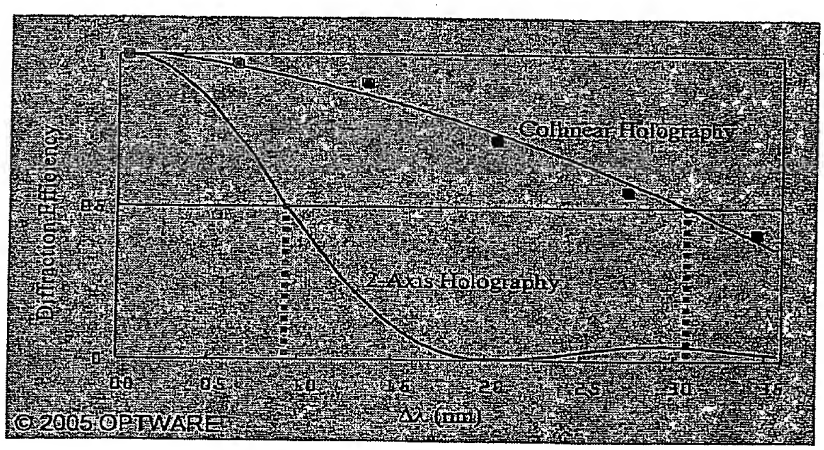

Figure 10. Wavelength margin analysis of diffraction efficiency at medium thickness of 500 μm.

The defocus margin and de-truck margin of the HVD compared with DVD's specifications are shown in Fig. 11 and Fig. 12. When the symbol error count is under 100, the reconstructed image can be decoded to user data completely. The results of the experiment indicate that both the defocus margin and de-truck margin of collinear technology are over six times larger than those of DVD's specifications.

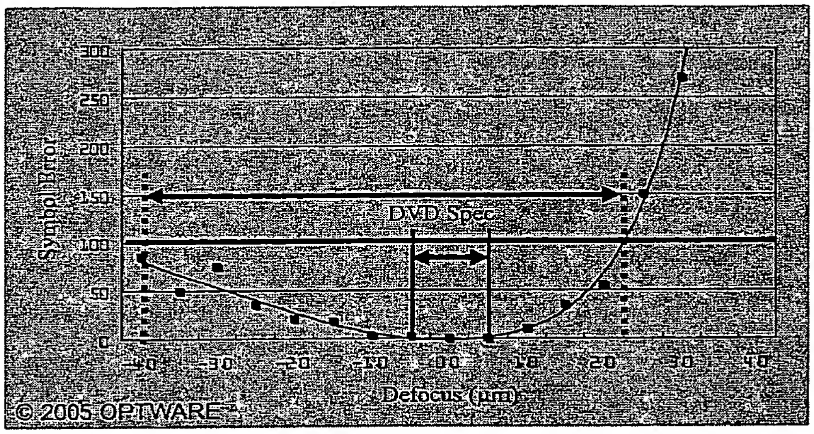

Figure 11. Defocus margin analysis of symbol error count compared with DVD specification.

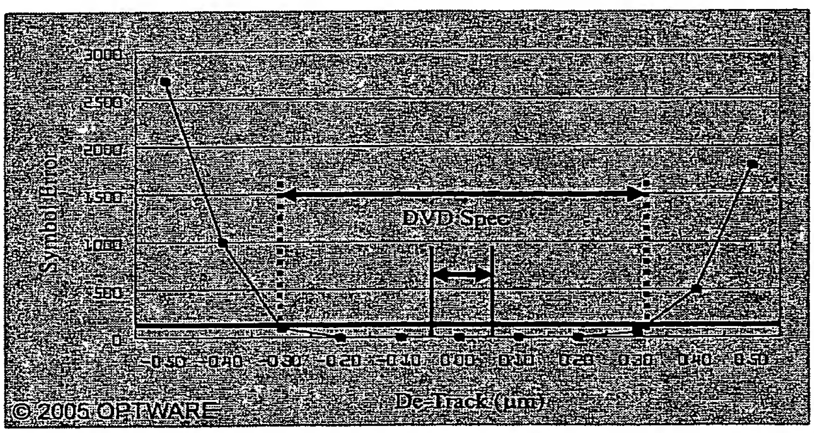

Figure 12. De-truck margin analysis of symbol error count compared with DVD specification.

6. CONCLUSIONS

We have developed a new reading and writing technology for HISS called Collinear Technology. Using this technology, 2-D page data can be recorded as volumetric holograms generated by an information beam and a reference beam that are bundled on the same axis, and irradiated on the recording medium through a single objective lens. The optical configuration and the dichroic disc structure suitable for the system are presented. The recording and reconstructing processes demonstrate that the proposed HVD system and disc structure are indeed very effective for materializing a small optical storage system with huge density. With its unique selectable capacity recording format of HVD shows both downward and upward compatibility of different disc capacities.

The tilt margin and wavelength margin of collinear technology are over eight and three times larger than that of conventional 2-axis holography. The number of symbol errors in the reconstructed data page images at different wavelengths is calculated and the data page can be decoded to reproduce the user data until the tilt angle of the disc is 0.18 degree and $\Delta\lambda$=3 nm of the light source, at which point the angle of the disc and the laser wavelength in the reconstruction process differs from those in the recording process. The wavelength margin is sufficiently large for a laser diode to be used as the light source of an HVD system. The defocus margin and de-truck margin of collinear technology are also over six times wider than those of DVD's specifications. These wide system margins enable us to design and to make small, practical and low cost HVD products more easily. Collinear technology can construct HVD systems with CD and DVD upper compatibility.

Further investigations are underway to develop the high power, small size and low cost Q-switch pulse laser, to test the reliability of the media, to decrease the image noise from the reconstructing process, to balance the data density and the transfer rate by incorporating newly designed optical and electronic components. Theoretical discussion is necessary to elucidate why the tilt and wavelength margins of collinear technology are large. An HVD system is only one of the applications of Collinear Technology. In the near future, Read-Only HVD driver systems and Holographic Versatile Card systems will be developed by OPTWARE Corporation. In future, Collinear Technology will be compatible with existing disc storage systems, like CD and DVD, and will enable us to expand its applications into other optical information storage systems.

HISS as a promising candidate of the next-generation of the storage equipments have been researched for tens of years after the principle was proposed [13]. They have never been commercially available. However, in July 2004, a dynamic reading and writing demonstration of a streaming video on an HVD using Collinear Technologies has succeeded in OPTWAR Corporation. HVD system as a product will be produced in 2006. Ecma International has created Technical Committee 44 (TC44) to develop a standardization strategy for HVD systems, initially based upon the Collinear Technologies. Ecma has ambitious goals: in December 2006 the new standards will be submitted to ISO for fast-track processing.

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